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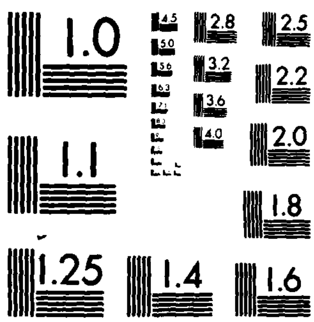

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ESTIMATING COSTS OF ICE DAMAGE TO PRIVATE SHORELINE STRUCTURES ON GREAT LAKES CONNECTING CHANNELS

Kevin L. Carey

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The possible extension of the navigation season through the entire winter or a portion thereof has been under consideration for the Great Lakes and the St. Lawrence Seaway for a number of years. To balance the benefits and costs of such an extension it is necessary to determine the damage costs to shore structures that might result from ice loosened by ship passage. This paper is concerned with the interconnecting channels of the Lakes where there is estimated to be $18,000,000 (1976 dollars) worth of small, private, vulnerable shore

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structures. Based upon information from Corps of Engineers Permits, aerial photos and site visits, probability estimates are given for winter damage on identifiable river reaches for differing season lengths. These are related to replacement costs and tables are given showing estimated annual damage costs. Possible solutions are given which vary with ice damage susceptibility.

PREFACE

This report was prepared by Kevin L. Carey, Research Civil Engineer, Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by the Winter Navigation Season Extension Program through the U.S. Army Corps of Engineers, Detroit District (NCE-IA-76-195).

This report was technically reviewed by S. Denhartog and L. Zabilansky.

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ESTIMATING COSTS OF ICE DAMAGE TO PRIVATE SHORELINE STRUCTURES ON GREAT LAKES CONNECTING CHANNELS

by

Kevin L. Carey

Problem

Privately owned shoreline structures include a great variety of designs and constructions. The majority are relatively lightweight structures (docks, platforms, boat houses, boat hoists, pile clusters, etc.) that serve their purposes but are not engineered to withstand nature's maximum forces.

In the connecting channels of the Great Lakes (Detroit River, St. Clair River, and St. Marys River), natural winter ice conditions have always subjected these private structures to forces that sometimes cause damage. Generally, this has resulted, through a self-selection process, in structures reasonably well suited in construction, extent, and location to withstand the prevalent range of forces created by ice covers, ice jams, and moving ice.

Under extended navigation conditions, the extent and disposition of ice in the connecting channels is altered. It is reasonable to suppose that there is a corresponding alteration in the type and extent of winter ice forces to which private shoreline structures are subjected. The problem, then, is to evaluate the change in the incidence and degree of damage incurred by private structures under extended navigation as compared to natural conditions or traditional navigation. Such change is important because it represents a cost (or a benefit) associated with the extended season navigation program.

The above is only an intermediate problem, the solution of which contributes to solving the larger problem: minimizing or preventing the ice damage to private shoreline structures created by an extended navigation season.

Location

The problem locations are the connecting channels of the Great Lakes: the Detroit River, St. Clair River, and St. Marys River. For the Detroit River, the specific area considered was the northern half of the eastern shore of Grosse Ile. Other portions of the Detroit River are judged to be unaffected by winter navigation. For the St. Clair River, the area considered includes the South Channel from the northeast end of the St. Clair Cutoff upstream to Russel Island, and the main channel from Algonac upstream to Port Huron. The North Channel and the Middle Channel are not considered in this study as they are not

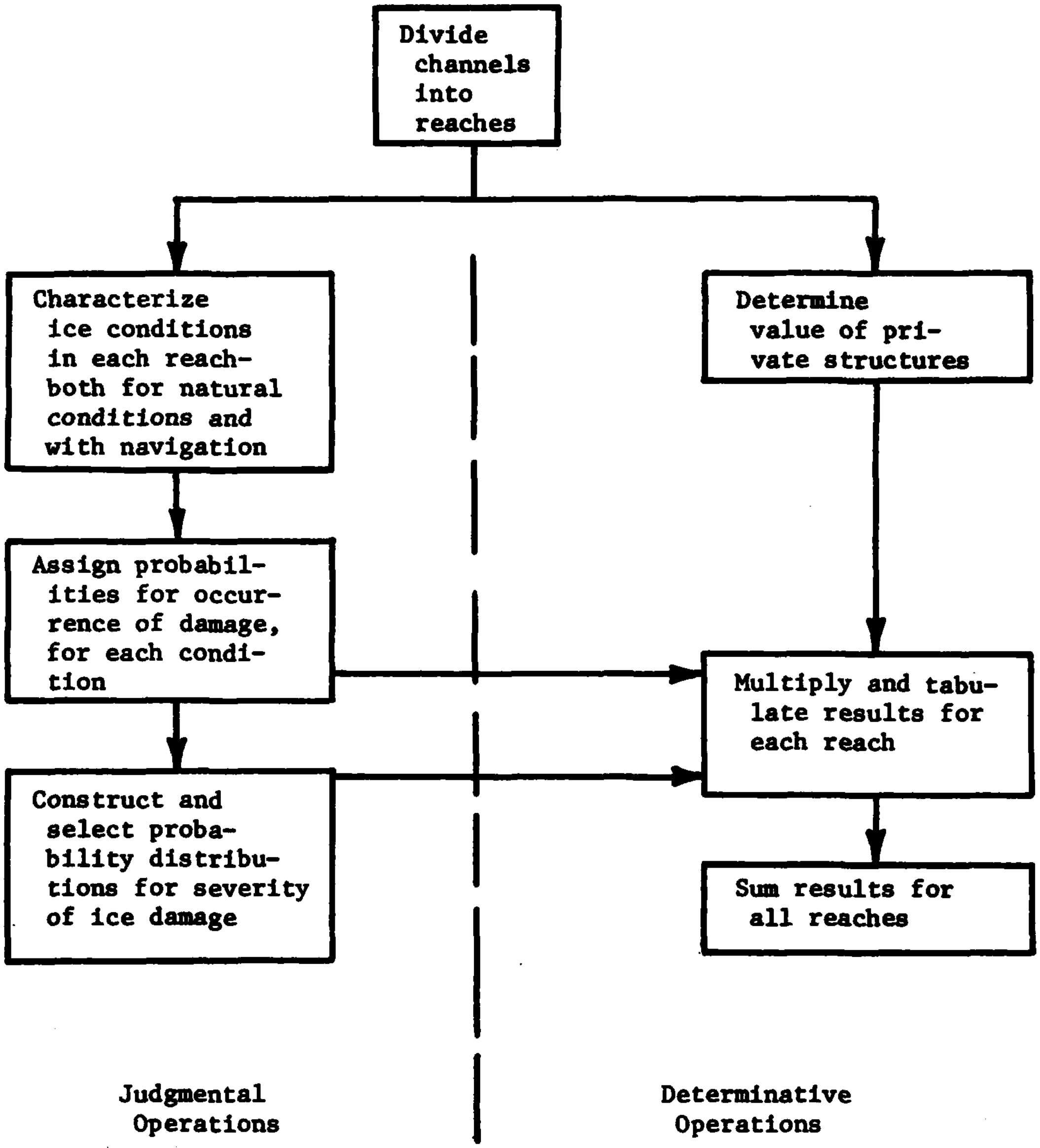


Figure 1. Flow chart for evaluating ice damage to private structures in Detroit, St. Clair, and St. Marys River.

involved in winter navigation. For the St. Marys River, the area considered extends from De Tour Passage in the vicinity of Point De Tour upstream to Whitefish Bay in the vicinity of Mosquito Bay and Brush Point.

Sources of Information

A great deal of detailed information on the private structures existing in the connecting channels was extracted from the files of the Permits Section, Detroit District, U.S. Army Corps of Engineers. These files amount to a structure-by-structure inventory, including photographs, descriptions, and statements of annotated aerial photographs, generally at a scale of 1:1200.

On-site examinations of private structures along the St. Clair River, plus studies of ice conditions and damage or distress to structures caused by ice, were conducted in mid-January 1976 by CRREL personnel in company with personnel from the Great Lakes Hydraulics and Hydrology Branch of the Detroit District.

Information regarding ice conditions, both natural and with winter navigation, was drawn from the knowledge and experience of CRREL personnel. This was supplemented by photographic and written documentation on file in the Great Lakes Hydraulics and Hydrology Branch, as well as by the knowledge and experience of Branch personnel.

The Technical Services Branch of the Engineering Division, Detroit District, provided unit cost estimates for the types of construction common among private shoreline structures.

The responses of structures to the forces of ice were integrated into the study from the knowledge, experience, and judgment of CRREL personnel. Similarly, the estimates of the likelihood of occurrence and severity of ice damage to private structures, which are discussed below, are based upon the experience and judgment of CRREL personnel.

Description of Problem

The problem statement (i.e. to evaluate the change in the incidence and degree of damage incurred by private structures under extended navigation) suggests a logical approach to a solution. An analytical-deterministic approach, in which actual ice forces are compared with stability and strength criteria for each structure, would lead to an assessment of potential damage under actual conditions of extended navigation. However, the data necessary for such an analysis are not extensive enough nor sufficiently documented to apply them with confidence to so great a number and variety of structures, ice conditions, and channel configurations.

Thus, a probabilistic approach was developed to assess both the incidence and degree of ice damage to structures. Even though analytical certainty is not obtainable, the probabilistic approach can adequately serve the planning function by providing information that is sufficiently precise to support planning conclusions and actions.

The probabilistic approach consists of characterizing the ice conditions, on a reach-by-reach basis, that occur naturally and under the several schemes of winter navigation. On the basis of these ice conditions and the channel characteristics within each reach, two probability estimates are made. First, estimates of the probability of occurrence of ice damage in each reach are made. This deals only with whether or not ice damage is likely to occur; it does not deal with how modest or extensive the damage is likely to be. Second, estimates are made which express the likely severity of ice damage in each reach in probabilistic terms. This is a judgmental indication of the degree of any ice damage that may occur in the reach.

There remains the need to translate the probability estimates into more tangible terms, such as dollar costs. This is done by expressing ice damage costs as a percentage of the total value of the structures.

Several options could be chosen for expressing the total value of privately owned shoreline structures. For example, value could be expressed as present depreciated value, or as cost of replacement by ice-resistant construction. The value figures under these two options would be very dissimilar. For the purposes of this study, it was decided to express value in terms of cost of replacement by like construction. (Any value option could be converted to another by employing appropriate multiplying factors, although this has not been done here.)

The procedures used in this study and described above can be seen more clearly in Figure 1, which shows their sequence and relationship to each other. This flow chart is somewhat simplified, because the initial division of the channels into reaches is based on a preliminary characterization of ice conditions in the various segments of the channels. A feedback process refines both the ice condition characterization and the reach division.

What follows is a summary description and discussion of the steps shown in the flow chart of Figure 1.

The division of the channels into reaches and the characterization of the ice conditions in each reach can best be treated together. The criteria employed in delineating reaches involved both the channel configuration and the ice conditions. Elements of channel configuration include channel width, expanding or contracting width, bends, bank height, and distance from bank to the navigation channel. The ice conditions considered are jamming, windrowing, degree of ice coverage, ice movement, typical floe sizes, accumulation patterns, and thicknesses.

To earn designation as a reach, a section of channel must be known or anticipated to have relatively uniform ice conditions throughout its length. In this way, the estimates of occurrence and severity of damage to structures can be made systematically while uncertainty is held to a minimum.

The preliminary division of channels into separate reaches led to the following breakdown:

Detroit River	2 reaches
South Channel St. Clair River	6
St. Clair River, main channel	11
St. Marys River	29

After consultation within CRREL and with District personnel, plus review of available documentation, it was determined that many reaches could be consolidated and still be regarded as having relatively uniform ice conditions and susceptibility to ice damage. As a result, the breakdown of reaches used in the study was simplified as follows:

Detroit River	1 reach
South Channel St. Clair River	1
St. Clair River, main channel	4
St. Marys River	9

Figure 2 shows the locations of these reaches, and Appendix A contains the detailed descriptions of the reaches and the ice conditions within each reach. The geographical locations of the endpoints of each reach are given in Appendix A, as referenced to the Lake Survey Recreational Craft Series, Chart 400, for the Detroit and St. Clair Rivers, and Lake Survey Charts 61, 62 and 63 for the St. Marys River. Also given in Appendix A are file numbers or aerial photo numbers (identifying documentation located in the Permits Section) which are applicable to each reach.

The narrative descriptions of ice conditions in Appendix A are given in two parts. First a qualitative description of natural conditions is presented, and then the influence of winter navigation on these natural ice conditions is discussed.

Judgmental Operations

It is important to note that these qualitative characterizations of ice conditions are a principal ingredient in the estimates of the probabilities of occurrence and severity of ice damage to private structures. While the descriptions of ice conditions are admittedly general, and may be imprecise in an absolute sense, they are believed to contain a high degree of consistency in a relative sense. Thus, the probability estimates generated from them will also possess a relative consistency which may be greater in importance than their absolute accuracy.

The estimates of the probability of occurrence of ice damage are detailed in Table 1 on a reach-by-reach basis. As noted earlier, these estimates apply to the likelihood of occurrence, not the severity of damage. Corresponding to the descriptions of ice conditions given in Appendix A, the probability estimates are given in two broad categories: natural ice conditions (i.e. the hypothetical case of no ice-season navigation), and with navigation (i.e. during some or all of the ice season).

A

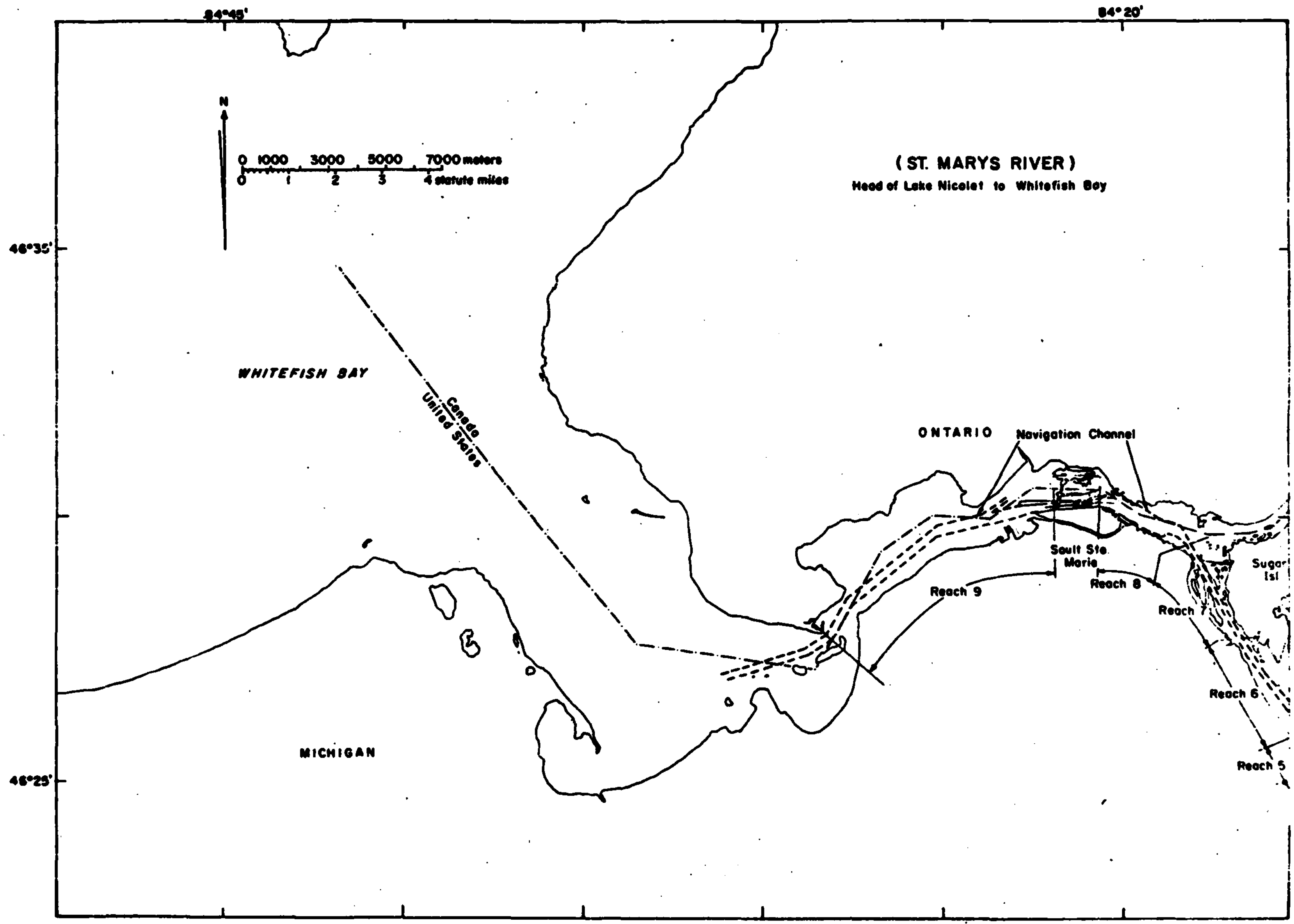
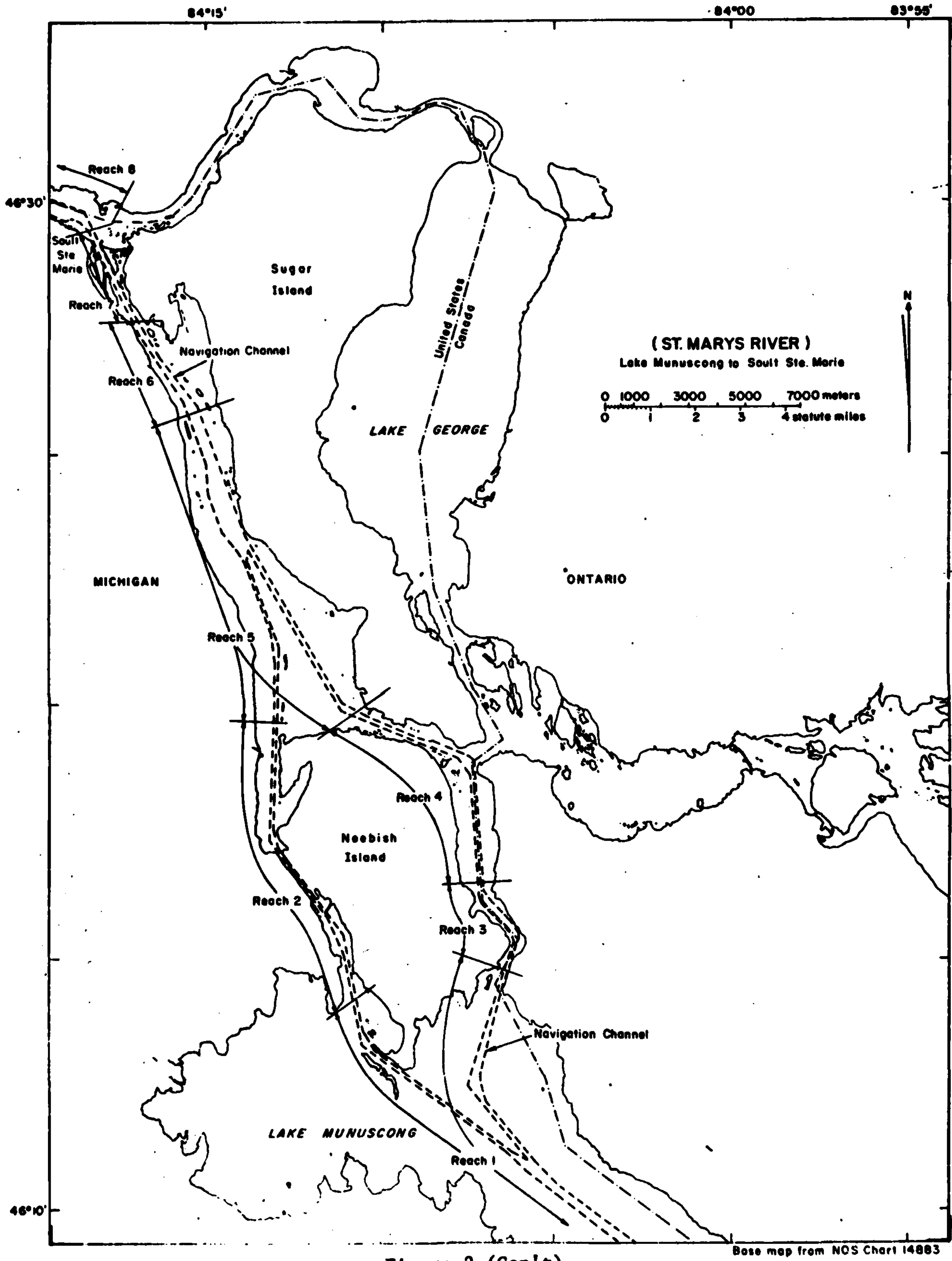


Figure 2. Maps of problem areas.



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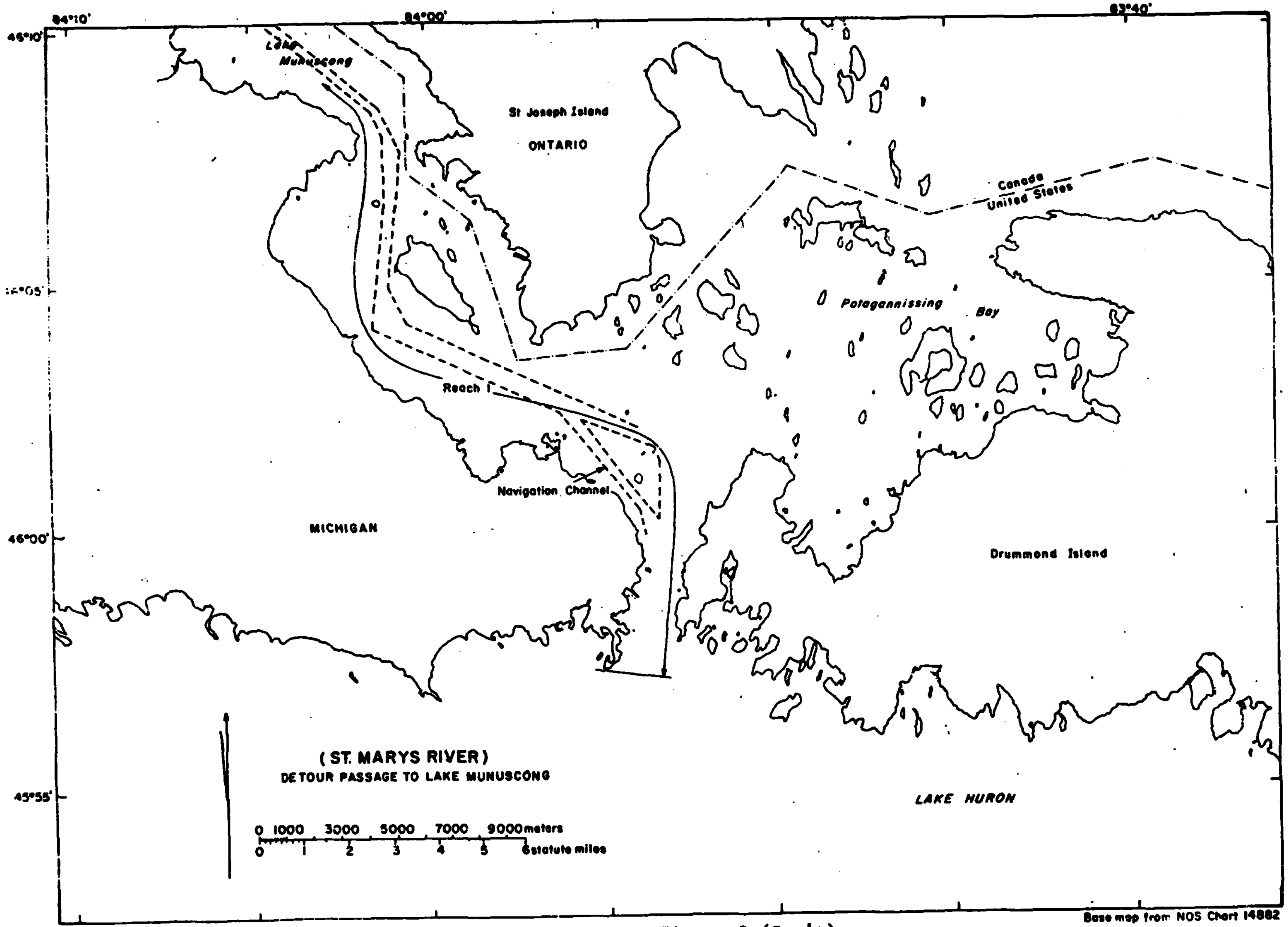

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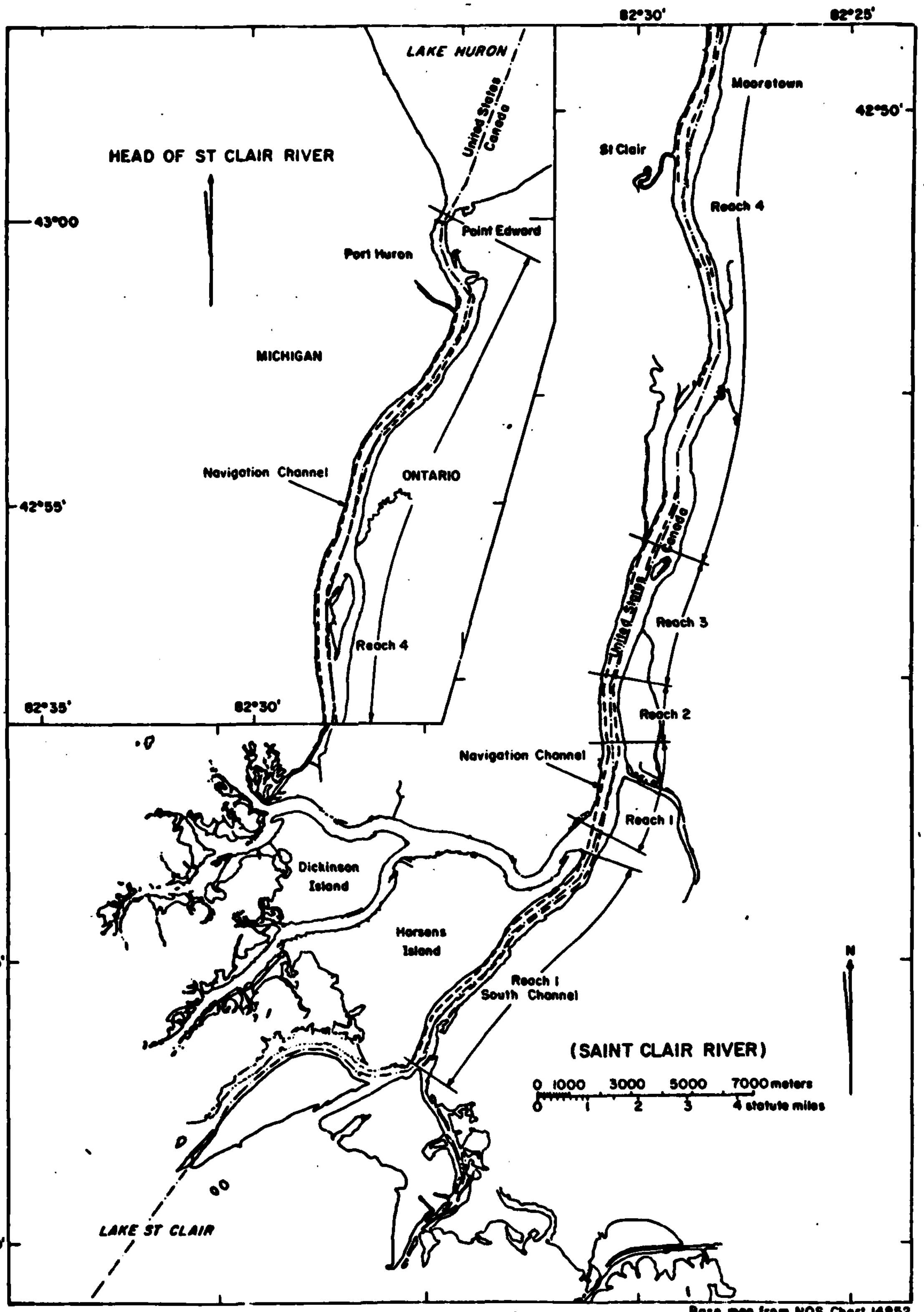

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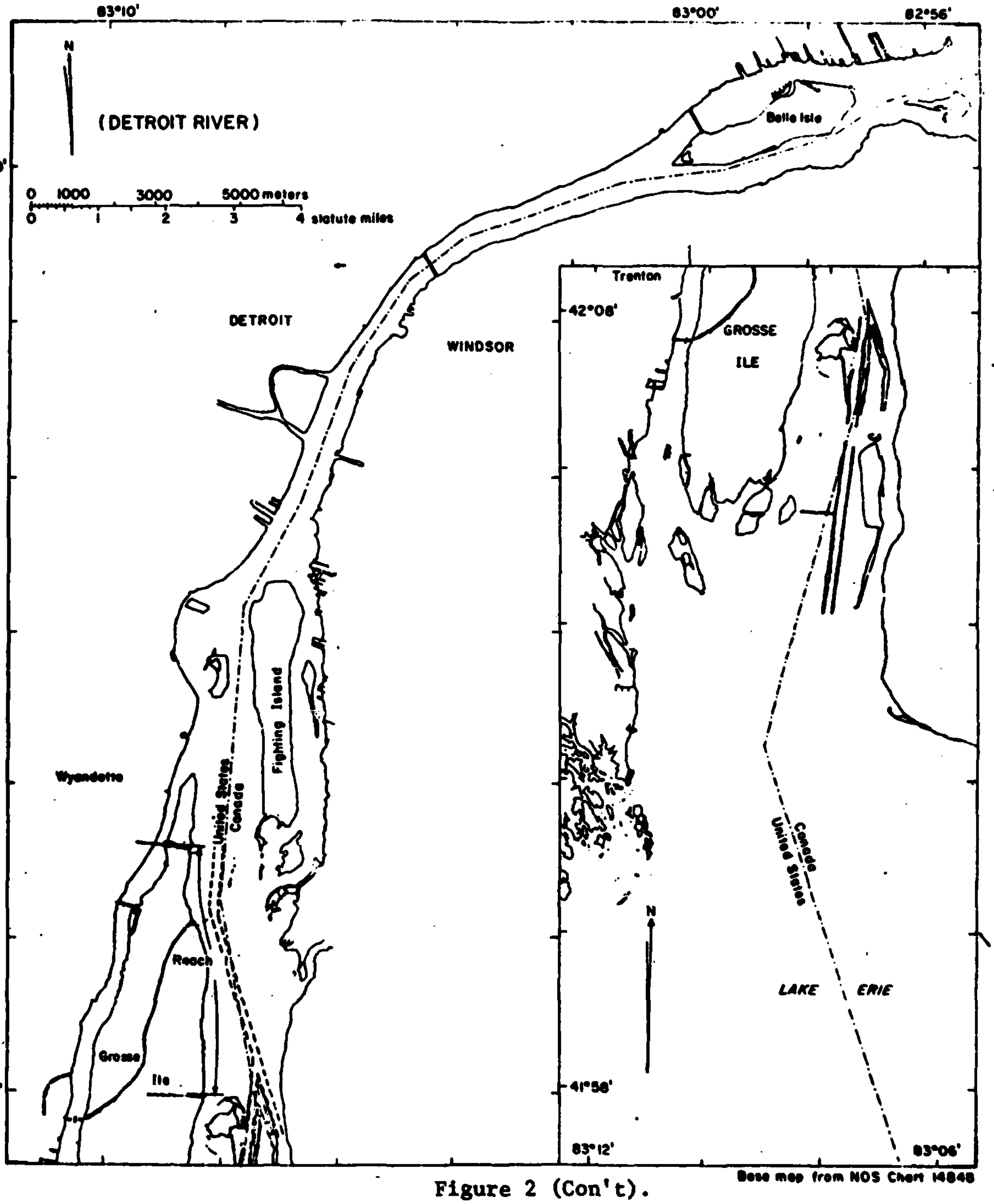


Base map from NOS Chart 14848

Figure 2 (Con't).

Within the broad "with navigation" category, there are three subdivisions: restricted season, traditional season, and extended season. A restricted season is a navigation season that is regulated to begin and end at specified times established such that ice would be nearly or totally absent during the beginning and end of the season; during a restricted season there would be no efforts to mitigate the effects of ice on navigation. The traditional season is one in which navigation extends as late into the winter as possible, and begins as early as possible, using icebreaker assistance to vessels when and where necessary, but without employing structural or other ice mitigation measures. The extended season concept involves a varied mix of structural and nonstructural measures for control and suppression of ice, plus icebreaker operations, all devoted to providing navigable conditions during what would normally be a period of ice-restricted navigation.

In Table 1, the extended season category is further subdivided into three parts, each representing one variation of the extended season concept: extended to the end of January, extended to the end of February, and extended year-round. For the Detroit and St. Clair Rivers, only the concept of year-round extension is under consideration; thus the two partial extension concepts are not addressed. However, all three concepts are being considered for the St. Marys River; hence all three are treated.

Listed under the appropriate headings for each reach are the judgmental estimates of the probability that damage will occur to private shoreline structures as a result of ice. The probabilities given under the natural ice conditions category are compatible with the narrative descriptions of natural ice conditions given in Appendix A. For any reach, this (natural ice conditions) probability is added to the probability listed under any with-navigation category.

Several points should be noted for the with-navigation categories. First, all probability estimates under the restricted navigation season concept are zero. This is due to a restricted season being indistinguishable from a no-navigation (natural ice conditions) case, insofar as impact on shoreline structures is concerned. Second, note that probabilities of occurrence generally increase under the range of concepts from restricted season to year-round season. The increasing risk reflects the increasing duration of the exposure of structures to ice forces during vessel operations. Third, under the year-round extended season concept, two separate probability estimates are provided to portray the differing expectations of damage occurrence according to whether or not structural mitigation measures are employed. In the absence of such measures, the likelihood of damage is estimated to be at a maximum. With such measures functional, damage is likely to be as probable as, or less probable than, under any other with-navigation concept. For two reaches the effect of mitigation is judged to be sufficient to reduce the probability below that of natural conditions; hence, negative values are shown.

Table 1. Probability of occurrence estimates

Reach	Probability of occurrence of ice damage							Severity category
	Natural ice conditions	PLUS	With navigation					
			Restricted season	Traditional season	Extended season			
					Lasting to 31 January	Lasting to 28 February	Lasting* year-round	
Detroit River								
1	10%		0%	5%	-	-	5%/- (No mitigation anticipated)	I
South Channel, St. Clair River								
1	20		0	15	-	-	25/20	III
St. Clair River, main channel								
1	40		0	30	-	-	50/-10	VI
2	35		0	20	-	-	35/-5	V
3	25		0	15	-	-	25/0	IV
4	10		0	10	-	-	10/5	II
St. Marys River								
1	15		0	5	5%	10%	15/5	I
2	20		0	20	20	25	30/15	IV
3	25		0	30	40	50	60/20	VI
4	25		0	20	20	25	30/15	III
5	20		0	10	15	20	25/10	II
6	25		0	30	40	50	60/20	IV
7	15		0	15	15	20	25/10	II
8	10		0	5	5	5	5/5	I
9	25		0	5	10	15	20/10	II

*Without/with mitigation measures

With estimates of the probability of occurrence established, the judgmental operations remain to be completed by estimating the likely severity of ice damage to structures. This is done by establishing six severity categories, and assigning a severity category to each reach as indicated in the right-hand column of Table 1. The severity categories are signified by Roman numerals, where I represents the expectation of least severe damage, and VI represents the expectation of most severe damage. Again, examination of the severity category assignments for each reach, in conjunction with the description of with-navigation ice conditions in Appendix A, will reveal a qualitative compatibility.

Each severity category is expressed graphically as a probability distribution function (cumulative likelihood) plotted against a parameter representing the degree of ice damage to structures. Figure 3 presents, in six separate plots, the probability distributions for the six severity levels. The curves yield estimates of the probability that damage costs will be less than or equal to any particular percentage of total structure value. Stated another way, the curves provide estimates of the damage costs, as a percentage of total structure value, that will not be exceeded at any particular probability level. For example, in severity category I, there is an estimated 30% probability that damage costs will not exceed 2% of structure value, a 60% probability that costs will not exceed 4% of total value, and a 90% probability that damage will not exceed 16% of value. By comparison, under severity category VI, at probability levels of 30, 60 and 90%, it is estimated that damage costs will be less than or equal to 29, 44, or 70% of structure value, respectively.

The plots of Figure 3 were constructed by first drawing and refining hypothesized probability density functions for each severity category, until the density functions were judged to be realistic and representative of the expected severity of damage. Then the probability distributions were generated by graphical integration of the density functions. The probability levels of 30, 60 and 90% were chosen for discussion and illustrative purposes only. Other probability levels could be examined as well. To say, for example, that the probability is 60% that the damage will be less than or equal to 4% of structure value is equivalent to saying that the probability is 40% that the damage will exceed 4% of structure value.

Determinative Operations

The determination of value of the private shoreline structures in the connecting channels relies, first of all, on the inventory data extracted from the files of the Permits Section, Detroit District. These data include counts of structures by type, size, condition, etc. Table 2 summarizes the number of structures within each reach by type.

The estimates of the costs of replacement by like construction were made by means of generalized unit-cost estimates provided by the Technical Services Branch, Engineering Division, Detroit District. These unit costs are detailed in Appendix B. These cost estimates could not be

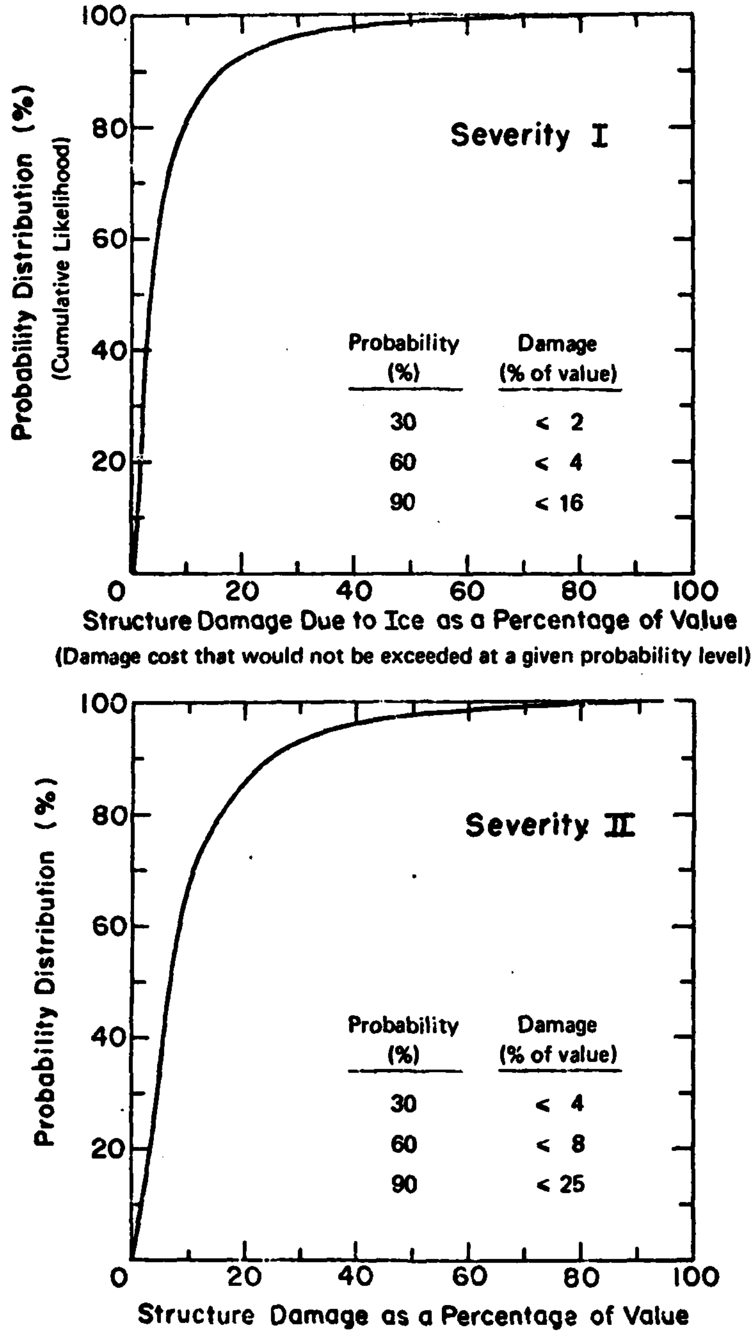
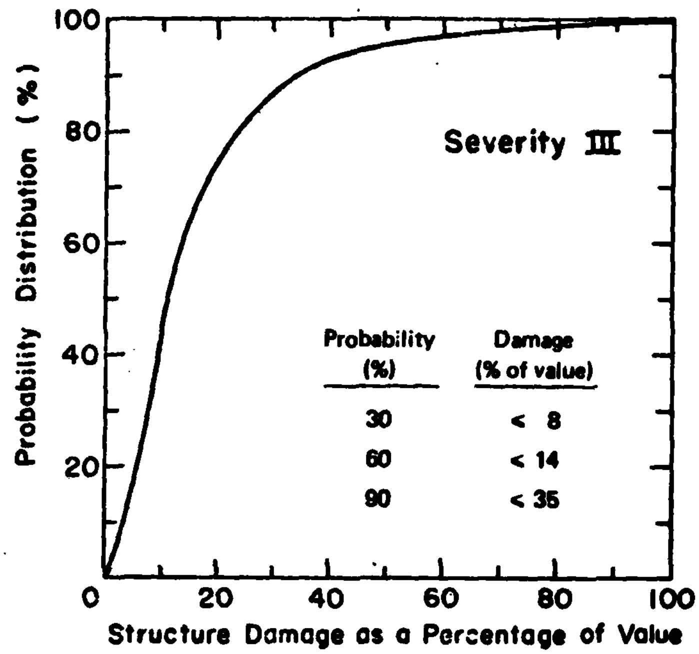
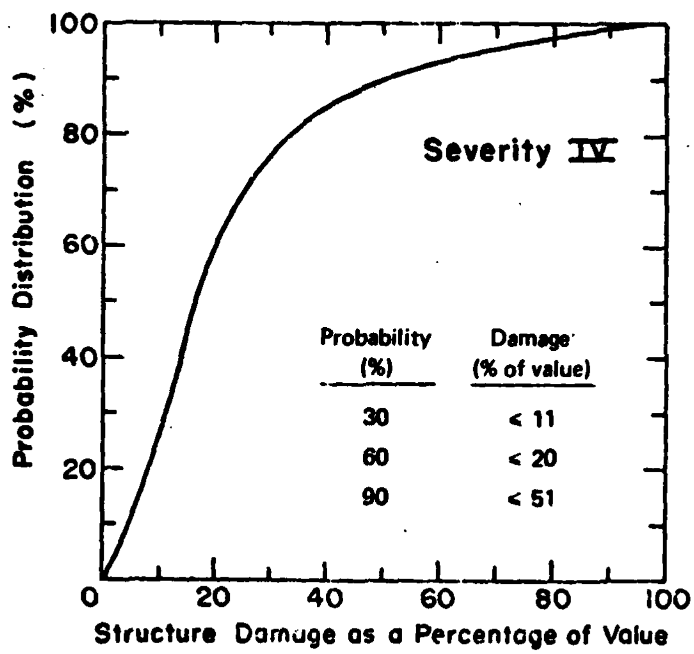


Figure 3. Probability of ice-damage occurrence at increasing levels of severity.





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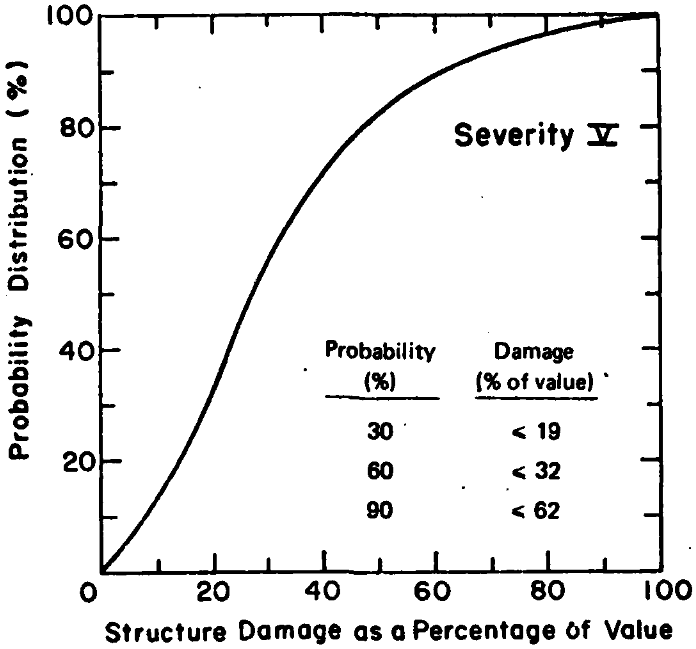

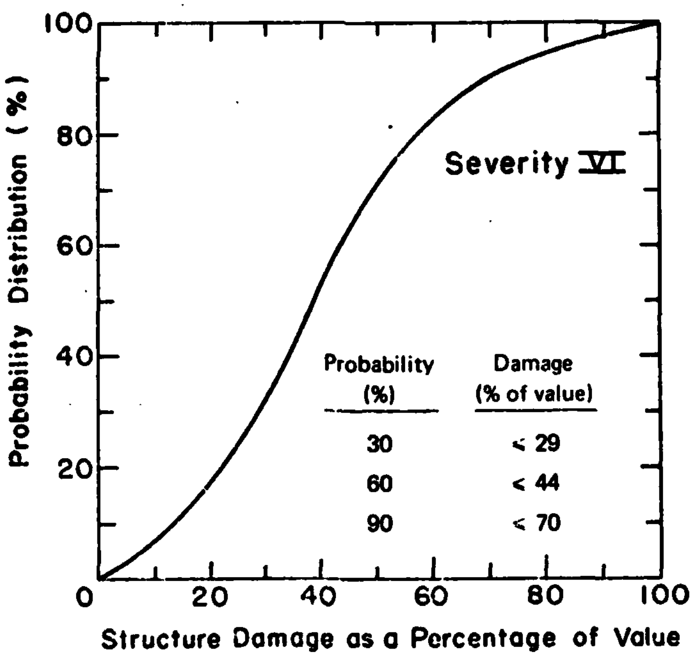

Figure 3 (Con't).

Table 2. Summary of structures by type and by reach

Reach	Walkway docks	End-dock Platforms	Pile clusters	Boat houses	Boat shelters	Boat hoists	Misc. (cribs, ramps, mooring piles, bulkheads, etc.)
Detroit River							
1	71	15	15	4	20	22	22
South Channel, St. Clair River							
1	128	81	113	13	41	72	16
St. Clair River, main channel							
1	54	20	55	7	12	6	12
2	21	5	17	3	5	1	17
3	105	55	115	13	32	22	28
4	440	192	347	97	80	99	137
Subtotal	620	272	534	120	129	128	194
St. Marys River							
1	71	17	0	7	3	1	32
2	119	25	2	13	1	0	34
3	42	14	0	6	0	0	29
4	13	5	0	2	0	0	6
5	36	0	5	3	0	0	5
6	31	3	2	2	0	0	5
7	15	3	9	3	0	0	6
8	10	1	20	1	0	0	1
9	25	5	0	0	2	0	28
Subtotal	362	73	38	37	6	1	146
TOTAL	1181	441	700	174	196	223	378

applied automatically in all cases. Instead, adjustments frequently had to be made for structures that were unconventional -- very large or very small, or unusual in some other way.

The combined result of the structure inventory and the unit-cost estimates is given in Table 3, which shows the value of private structures within each reach. The value of structures in the separate reaches varies widely because of differences in the concentration of structures, but more significantly because of large differences in the lengths of the reaches.

The results of the final steps in the flow chart of Figure 1 are given in Table 4. For each reach, and for each season concept, the value of the structures (Table 3) has been multiplied by the probability of occurrence (Table 1). The result has then been multiplied by the percent damage associated with one of three selected probability levels (30%, 60%, or 90%) according to the appropriate severity category (Fig. 3).

Corresponding to the probability distributions of Figure 3, the data of Table 4 represent upper limit annual damage cost estimates in 1976 dollars. That is, the annual damage costs are estimated to be less than or equal to the amounts shown. For example, under natural conditions, it is estimated that there is a 90% probability that the annual ice damage costs for all the channels will not exceed $1,275,600. This implies an estimate that there is a 10% chance that the damage will exceed this amount. Similarly, the estimate of a 60% chance that the annual damage costs will not exceed $561,900 implies a 40% estimated probability that they will.

The total estimates shown in Table 4 for the partially extended seasons (31 January, 28 February) are made using subtotals for year-round operation (without mitigation) in the Detroit and St. Clair Rivers, since it is expected that season extension will not be partial for these channels, even if it is partial for the St. Marys River. Similarly, the subtotal for Detroit River year-round operation without mitigation is used in preparing the total for year-round operation with mitigation, since no mitigation measures are envisioned for the Detroit River.

Possible Solutions

1. Pile Cluster Protection

Description - The selective placement of pile clusters adjacent to private shoreline structures would provide hard points to protect those structures from ice forces, primarily horizontal forces. The number and position of clusters for each structure would have to be determined according to the ice conditions in the area and the exposure of the structure. This solution would not offer significant protection against vertical forces.

Economic Impact - Examination of Table 2 reveals that there is a total of 1551 walkway docks, boat houses, and boat shelters, the structures

Table 3. Value of structures by reach

Reach	Value or cost of replacement by like construction ($1000's)
Detroit River	
1	$ 1,582.8
South Channel, St. Clair River	
1	2,420.3
St. Clair River, main channel	
1	746.9
2	350.3
3	2,083.2
4	6,725.1
Subtotal	9,905.5
St. Marys River	
1	617.5
2	1,495.8
3	531.6
4	356.4
5	245.1
6	190.8
7	162.7
8	159.8
9	435.5
Subtotal	4,195.2
TOTAL	$18,103.8

Table 4. Upper limit - Annual ice damage costs to private shoreline structures for three probability levels (30%, 60%, 90%).

	Probability levels	Detroit River Reach 1	Detroit River Sub-total	South Channel St. Clair R. Reach 1	South Channel St. Clair R. Sub-total	St. Clair River Reaches 1	2	3	4	St. Clair River Subtotal	St. Marys River Reaches 1	2	3	4	5	6	7	8	9	St. Marys River Subtotal	TOTAL
Natural conditions	30%	3.2	3.2	38.7	38.7	86.6	23.3	57.3	26.9	194.1	1.9	32.9	38.5	7.1	2.0	5.2	1.0	0.3	4.4	93.3	329.3
or	60%	6.3	6.3	67.8	67.8	131.4	39.2	104.2	53.8	328.6	3.7	59.8	58.5	12.5	3.9	9.5	2.0	0.6	8.7	159.2	561.9
Restricted season	90%	23.3	23.3	169.4	169.4	209.1	76.0	265.6	168.1	718.8	14.8	152.6	93.0	31.3	12.3	24.3	6.1	2.6	27.2	364.1	1275.6
Traditional	30%	4.7	4.7	67.8	67.8	151.6	36.6	91.7	53.8	333.7	2.5	65.8	84.8	12.8	2.9	11.5	2.0	0.5	5.2	188.0	594.2
navigation	60%	9.5	9.5	118.6	118.6	230.0	61.6	166.7	107.6	565.9	4.9	119.7	128.7	22.5	5.9	21.0	3.9	1.0	10.5	318.1	1012.1
season	90%	38.0	38.0	296.5	296.5	366.0	119.4	425.0	336.3	1246.7	19.8	305.1	204.7	56.1	18.4	53.5	12.2	3.8	32.7	706.3	2287.5
Extended navigation	30%	-	-	-	-	-	-	-	-	-	2.5	65.8	100.2	12.8	3.4	13.6	2.0	0.5	6.1	206.9	735.5
season	60%	-	-	-	-	-	-	-	-	-	4.9	119.7	152.0	22.5	6.9	24.8	3.9	1.0	12.2	347.9	1253.9
(to 31 January)	90%	-	-	-	-	-	-	-	-	-	19.8	305.1	241.9	56.1	21.4	63.3	12.2	3.8	38.1	761.7	2839.0
Extended navigation	30%	-	-	-	-	-	-	-	-	-	3.1	74.0	115.6	14.3	3.9	15.7	2.3	0.5	7.0	236.4	765.0
season	60%	-	-	-	-	-	-	-	-	-	6.2	134.6	175.4	24.9	7.8	28.6	4.6	1.0	13.9	397.0	1303.0
(to 28 February)	90%	-	-	-	-	-	-	-	-	-	24.7	343.3	279.1	62.4	24.5	73.0	14.2	3.8	43.6	868.6	2945.9
Year-round navigation	30%	4.7	4.7	87.1	87.1	194.9	46.6	114.6	80.7	436.8	3.7	82.3	131.0	15.7	4.4	17.8	2.6	0.5	7.8	265.8	794.4
season	60%	9.5	9.5	152.5	152.5	295.8	78.5	208.3	161.4	744.0	7.4	149.6	198.8	27.4	8.8	32.4	5.2	1.0	15.7	446.3	1352.3
(without mitigation measures)	90%	38.0	38.0	381.2	381.2	470.5	152.0	531.2	504.4	1658.1	29.6	381.4	316.3	68.6	27.6	82.7	16.3	3.8	49.0	975.3	3052.6
Year-round navigation	30%	-	-	58.1	58.1	65.0	20.0	57.3	40.4	182.7	2.5	57.6	69.4	11.4	2.9	9.4	1.6	0.5	6.1	161.4	406.9
season	60%	-	-	101.7	101.7	98.6	33.6	104.2	80.7	317.1	4.9	104.7	105.3	20.0	5.9	17.2	3.3	1.0	12.2	274.5	702.8
(with mitigation measures)	90%	-	-	254.1	254.1	156.8	65.1	265.6	252.2	739.7	19.8	267.0	167.5	49.9	18.4	43.8	10.[illegible]	3.8	38.1	618.5	1650.3

most likely to merit protection. If it is assumed that about half (800) of these would require protection, and that each structure would call for three clusters, then the construction cost (using the unit cost given in Appendix B) would be $3,225,600.

Significant Environmental/Social Impact - No environmental impact would be envisioned from installation of the pile clusters. Social impacts may take the form of restrictions on the usability or serviceability of the structures being protected. There may also be objections from owners of private structures on other grounds, such as aesthetics.

2. Removable Structures

Description - Several concepts exist for structures that can be removed from the waterway and stored on shore during the winter. Docks constructed on large-diameter wheel assemblies, and docks or shelters on floats and guyed in place, are already used in various parts of the country. There is also the idea of cantilevered structures whose foundations and supports are located on shore. These could be raised and swung to a shore position during the ice season, or they could simply be raised above the level where ice forces would affect them.

Economic Impact - Since a multitude of designs for removable structures would be employed, and since designs are not generally standardized, it is difficult to establish costs. An estimate may be made by assuming that removable structures would range in cost from 1.5 times to 4 times the cost of the conventional structures they would replace, with an average of 2.5 times the conventional structure cost. Now, if it is assumed that structures amounting to 25% of the value of present structures are chosen for replacement, the construction cost would be

$$\$18,103,800 \times 0.25 \times 2.5 = \$11,314,875.$$

Significant Environmental/Social Impact - Environmental impacts are not foreseen as a result of this solution. Social impacts, if any, would likely take a form similar to the pile cluster solution, that is, objections regarding usability, serviceability, aesthetics, etc.

3. Restoration

Description - Before the start-up of operational season extension, the present or "before" conditions of private shoreline structures would be thoroughly documented. This would permit a comparison with later damaged conditions resulting from winter navigation. Then, damaged structures could be restored equitably to the "before" conditions. Aside from the actual restoration work, this solution would involve a major continuing effort in documentation and damage assessment.

Economic Impact - If it is assumed that, as an average, the structures in the "before" condition have 50% of their useful life remaining, then the cost of restoration to the "before" conditions (as opposed to

replacement by new and like construction) would be 50% of the damage costs shown in Table 4. This is an annual cost. Initial personnel costs for documentation and assessment are estimated to be equivalent to five man-years. Continuing annual personnel costs for assessment and documentation of new construction are estimated at one man-year.

Significant Environmental/Social Impact - No environmental impacts would be anticipated from this solution. Inconvenience to the private structure owners and impaired public relations are the possible social impacts.

4. Financial Reimbursement

Description - Under this solution, private property owners would receive simple financial reimbursement for structures damaged during winter navigation, in amounts sufficient to permit restoration by new but like construction. Property owners would be free to use their reimbursement for reconstruction duplicating the original construction, or for removable structures, strengthened structures, or protected structures. Thus under this solution, the private owner's incentive to avoid yearly reconstruction would possibly lead to a slow "weeding-out" of vulnerable and damage-prone structures.

Economic Impact - The costs of financial reimbursement would be equivalent to the estimated upper-limit annual damage costs detailed in Table 4. The actual costs may be lower due to under-reporting by the private owners. Personnel costs are estimated at a continuing level of one man-year.

Significant Environmental/Social Impact - This solution does not appear to impose any adverse environmental impacts. As with the previous solution, the possible social impacts are in the areas of inconvenience to the private owners and impaired public relations.

Selected Solution

There is no one possible solution that clearly recommends itself as applicable in all cases. It is believed that a combination of the several solutions should be selected.

Rationale for Selection - Because of the wide variations in ice conditions and susceptibility to damage, a multi-faceted approach is judged to be most cost-effective. For some reaches, removable structures would offer the only guarantee of freedom from severe and continuing ice damage. In other reaches, selected use of pile clusters will permanently solve damage problems.

Detailed Description - See under Possible Solutions

Economic Impact - See under Possible Solutions

Significant Environmental/Social Impact - See under Possible Solutions.

Action Plan - Since the costs of the solutions are linked to the damage cost estimates described and given earlier, the key to evaluating the solution is to refine the damage cost estimates. While the damage cost estimates discussed earlier are not represented as objectively accurate, they are believed to have a relative internal consistency, which has been arrived at through application of a systematic method.

This systematic method serves as a model which can be used with real data to produce refined estimates. By collecting actual damage data from the field, both in terms of incidence and cost, we can establish more accurate probability estimates and probability distributions. Some progress toward this end could possible be made by assembling whatever data exist on past incidents of ice damage to private structures. In the light of real data, the reach break-down may be altered somewhat, but the model framework would still be serviceable.

Along with this refinement of the judgmental side of the model, the determinative side could also be refined by collecting actual construction cost data. Figures for original construction and complete reconstruction, as well as for repair of ice-induced damage, would permit a strengthening of the relationship of damage costs, as probability distribution functions, to total structure costs.

APPENDIX A

Description of reaches and ice conditions

<u>Detroit River</u> - East shore of Grosse Ile

<u>Reach 1</u>
Sheets 7&8
Chart No. 400

From near Macomb Road at East River Road (in the vicinity of the north end of Livingstone Channel) northward to the north end of East River Road. File numbers 2554-75 to 2635-75.

<u>Ice Conditions</u>

<u>Natural</u>

A uniform, stable ice cover may form in this reach, occurring either as shore ice or as a more extensive cover. This area is characterized by quiet water; thus the ice deteriorates in place, while most of the moving floe ice passes along the Canadian side towards the Amherstburg Channel. There can be vertical movement of the ice cover as a result of wind set-up changes in the level of Lake Erie; horizontal ice movement is minor, due only to wind and wave action rather than water flow.

<u>Navigation</u>

Because of the distances between the shoreline and the navigation channel, and the natural ice conditions in this area, navigation does not alter the ice conditions at the shoreline.

<u>South Channel - St. Clair River</u>

<u>Reach 1</u>
Sheets 39-42
Chart No. 400

From 42°33'N, 82°36.5'W (1/2 mile downstream from junction of St. Clair Cutoff) upstream to the northeast end of Russel Island.
File numbers 2198-75 to 2333-75, plus (for Russell Island) map key numbers 1 to 17 (no file numbers).

<u>Ice Conditions</u>

<u>Natural</u>

This channel is subject to the formation of stable shore ice, extending generally out to the 6-ft depth-line or out to the channelward end of shore structures. Otherwise, it becomes ice-filled only after Lake St. Clair freezes over, and floe ice coming down the St. Clair River progressively covers the channel from the south end to the north end. Horizontal movement of the shore ice is negligible. Vertical movement of the shore ice, due to wind-induced changes in the level of Lake St. Clair, is confined to the early season when shore ice is thin. Thus the vertical forces resulting

from this movement are nil. Also, large level changes do not generally occur due to ice jamming, since jams form upstream of the South Channel. During the spring, ice moves out of the channel along a shear zone at the offshore edge of the shore ice. Later, when the shore ice is melted, the moving floe ice remains generally confined to the deeper (>6 ft) parts of the channel and does not interfere with shore structures, which at this time lie in open water.

Navigation

Vessel movement appears to have little or no effect on the natural compacted floe field. Small horizontal and vertical forces, induced by vessel operation, are possible.

St. Clair River - Main Channel

Reach 1
Sheet 42,
Chart No. 400

From Minnich's Boats (across from the shoal at the north end of Russell Island) upstream to Algonac State Park boat ramp.
Photos 21-07 to 21-11.

Ice Conditions

Natural

Ice jams consistently form in this reach, due to the accumulation of ice floes coming downstream from Lake Huron. The frequency and severity of jamming is highly dependent on the supply of ice from Lake Huron. Pressure in the floe field forces ice pieces up on edge and produces piling and layering, so that the thickness of the jam may reach 8 to 10 ft. The jam stabilizes by freezing together, and when weather or river conditions allow it to break and release, the movement and turning of the ice en masse damage structures. Level changes resulting from the jam may be as much as a 1- to 2-ft increase in stage. This causes uplift forces on adfrozen structure piles.

Navigation

The passage of ships through the ice jam in this reach continues until the jam is too heavy to be traversed. To get through the jam, vessels sometimes travel at higher than normal speeds, especially when headed downstream. This produces waves in the channel which are propagated through the floating ice jam to the shore. Also, the vessels pack ice together tightly at the edges of the vessel track, leading to localized densification of the jam. When ships become stuck in the jam, icebreaker assistance is required, and the icebreaker operations impose added vertical and horizontal movements on the ice at the shore.

Reach 2 Sheets 42 & 43 Chart No. 400	From Algonac State Park boat ramp upstream to 42°40'N. Photos 21-42 to 21-15.
Ice Conditions	Same as Reach 1, but to a diminished degree.
Reach 3 Sheet 43, Chart No. 400	From 42°40'N upstream to McLouth Marine Yards at Marine City. Photos 21-16 to 21-24.
Ice Conditions	Same as Reach 2, but to a diminished degree.
Reach 4 Sheets 44-49 Chart No. 400	From McLouth Marine Yards at Marine City upstream to Dunn Paper Co. at the head of the river at Port Huron. Photos 21-25 to 21-89.

Ice Conditions

Natural — This reach is upstream from locations where ice jams commonly occur. Shore ice normally forms in this reach, but the principal form of ice in the reach is un-jammed ice floes and brash floating downstream. Ice floes may be released in quantity at times from Lake Huron, or they may be sparse as a consequence of the formation of a natural ice bridge at the mouth of Lake Huron. Ship penetration of the ice bridge can cause increases in floating ice in the reach, until the ice bridge re-forms. Generally little or no damage to structures occurs due to ice north of Fawn Island at the southern end of the reach.

Navigation — Due to the light and stable shore ice, and the generally free-flowing floating ice in this reach, navigation does not alter the natural ice conditions. Small vertical forces on the shore ice, induced by waves, are possible.

St. Marys River

Reach 1 Chart Nos. 61 & 62	From Point De Tour upstream through lake Munuscong to Kemps Point at the southern end of West Neebish Channel, and to a point just south of Black Buoy No. 17 (3/4 mile south of Johnson Point) at the southern end of Munuscong Channel (also called Middle Neebish Channel). Photos 15-11 to 15-3; 16-10 to 16-2; 17-1 to 17-5; 18-21 to 18-1; 19-9 to 19-1; 20-11 to 20-1; 21-5 and 21-3; 22-8, 22-6, 22-2; 23-11 to 23-3; 24-5 to 24-1; 25-9 to 25-3; 26-5 to 26-1; 63-13 to 63-3; 65-2 to 65-6; 66-11 and 66-9; and 67-13 to 67-5.

Ice Conditions

Natural — The ice conditions in this reach, from Lake Huron up to the head of Lake Munuscong, are essentially lake ice conditions, with extensive shore-fast ice and a continuous uniform stable ice cover. There may be vertical movement of the ice cover due to seiche action in Lake Huron, and in the spring there may be horizontal movement of drifting floes due to wind action.

Navigation — Due to the distances that commonly exist between the shoreline and the navigation channel, and due to the generally stable ice conditions that occur naturally in this reach, navigation does not affect the natural ice conditions at the shoreline. While navigation through the ice cover creates windrows and brash at the vessel track, none of the effects of navigation extend far enough to reach shore.

Reach 2
Chart No. 62 — From Kemps Point on the west shore, and a small point on Neebish Island on the east shore, upstream through the West Neebish Channel rock cut to a point one-half mile north of the mouth of the Charlotte River. Photos 62-12 to 62-2; 61-14 to 61-8.

Ice Conditions

Natural — Thick shore ice forms in this reach, and natural uplift due to Lake Huron seiches moves this ice vertically. Broken ice moves through the reach during spring break-up.

Navigation — West Neebish Channel is generally closed to winter navigation, but navigation immediately before and immediately after closure can take place with ice present in the channel. Due to the width restrictions in the channel, vessel operations can cause both horizontal and vertical movement of any shore ice that is present. Structure damage has been claimed due to ice and navigation in both early winter and in spring.

Reach 3
Chart No. 62 — From a point just south of Black Buoy No. 17 (3/4 mile south of Johnson Point) at the southern end of Munuscong Channel (also known as Middle Neebish Channel), upstream along Munuscong Channel to just north of Point of Woods Range Lights (on the east shore of Neebish Island). Photos 67-3 & 67-1; 68-13 & 68-11.

Ice Conditions

Natural — Thick stable ice forms at shore and in the middle of the channel. Broken ice moves through the reach during spring break-up.

Navigation — Navigation and icebreaker operations cause cracking of ice near shore and out in the channel, pile-up of ice blocks due to horizontal ice movement, and rapid water-level changes which cause vertical ice movement. Based on damage reports received in Detroit District, it has been estimated 40-50% of the damage costs which occur on the St. Marys River are incurred between Johnson Point and Dark Hole. These damages have occurred during every winter that has had navigation, and it appears that the severity of damages is directly related to the length of the winter operating season.

Reach 4
Chart No. 62 — From just north of Point of Woods Range Lights (on the east shore of Neebish Island) upstream along Munuscong Channel and Middle Neebish Channel to a point on the north shore of Neebish Island southwest of the intersection of Course 6 and Course 5 (upbound courses). Also includes the southern shore of Sugar Island from Harwood Point upstream along Middle Neebish Channel to a point east-northeast of the intersection of Course 6 and Course 5 (upbound). Photos 68-9 to 68-1; 69-10 to 69-6; 11-10 to 11-4.

Ice Conditions

Natural — Thick stable ice forms a continuous cover in this reach. Broken ice moves through the reach during spring break-up.

Navigation — Vessel operations during winter in this reach cause cracking and some horizontal and vertical movement of the ice cover, but since turning conditions are not difficult, the degree of disruption of the ice cover is not severe. Also, icebreaker assistance to vessels is not commonly required in this reach. Thus the overall effect of navigation on ice conditions at the shorelines is slight to moderate.

Reach 5
Chart No. 62 — From one-half mile north of the mouth of the Charlotte River upstream to one-half mile south of Six Mile Point (all along the mainland shore), and from a point east-northeast of the intersection of Course 6 and Course 5 (upbound courses) upstream to a triangulation station (14LN) opposite Six Mile Point (all along the Sugar Island shore).

Photos 61-6, 61-4; 60-31 to 60-15; 70-7 to 70-1; 71-8 to 71-4; 72-17 to 72-11.

Ice Conditions

Natural

Winter ice forms a continuous cover in this reach, and broken ice moves through the reach during spring break-up.

Navigation

Vessel operations when ice is present in this reach apparently do not cause distress to the ice cover that is felt at the shorelines. Presumably, navigation causes some minor horizontal and vertical movement of the ice, but icebreaker activities are generally limited to maintaining the vessel track, and the effects of vessel operations on the ice conditions at the shoreline are slight.

Reach 6
Chart No. 62

From one-half mile south of Six Mile Point upstream to 0.2 mile north of Frechette Point (all along the mainland shore), and from a triangulation station (14LN) opposite Six Mile Point upstream to a traingulation station (10A) opposite Frechette Point (all along the Sugar Island shore and including Wasig Bay). Photos 60-13, 60-11; 59-11; 59-9; 72-9 to 72-1; 60-8.

Ice Conditions

Natural

Thick stable ice forms a continuous cover in this reach. During spring break-up, broken ice moves through the reach.

Navigation

Navigation in this reach causes a longitudinal crack to form in the ice cover near the mainland shoreline. This crack progressively widens during the ice season, possibly due to the turning action of vessels at the southern end of the reach. The crack, which has occurred during each winter navigation season, causes distress to shoreline structures by imposing horizontal forces on the parts of the structure on the channel side of the crack. Because of the freedom that the crack gives to the channel ice cover, it may also undergo vertical movement as a result of vessel passages. Apparently the Sugar Island shoreline is unaffected by navigation in this reach.

Reach 7
Chart No. 62

From 0.2 mile north of Frechette Point upstream to 0.4 miles northwest of Mission Point (all along the mainland shore), and from a triangulation station (10A) opposite Frechette Point upstream to 0.5 mile northwest of Sugar Island ferry landing (all along the Sugar Island shore).
Photos 59-7 to 59-3; 60-6 to 60-2.

Ice Conditions

Natural — This reach is a transition zone between generally stable continuous ice cover downstream, and generally open water upstream. Stable ice cover and shore ice forms in the side channels and around the islands. Under natural conditions the Little Rapids Cut may have shore ice or become ice covered.

Navigation — Broken ice is locked through the Soo Locks, and this progressively fills the Little Rapids Cut with compacted ice. At times during extended navigation, an ice boom has been in place at the head of the reach, limiting the amount of ice floes entering the Little Rapids Cut. When the ice boom has not been present and compacted floes have filled the cut, vessel operations have often required icebreaker assistance, disrupting much of the compacted floe field. However, this activity generally has little or no impact on shoreline structures in this reach.

Reach 8
Chart No. 63 — From 0.4 miles northwest of Mission Point upstream to the area downstream from the Soo Locks, adjacent to the Corps of Engineers warehouse.
Photos 59-1, 1-6, 1-4.

Ice Conditions

Natural — This reach generally has open water with light shore ice.

Navigation — Under extended season navigation, broken ice is locked through the Soo Locks, and so ice floes move through the reach. Floating ice may accumulate at the downstream end of the reach as the compacted floe field in Reach 7 progresses upstream. If an ice boom is present in Reach 7, the accumulation of floating ice in Reach 8 will progress farther upstream. Vessel and icebreaker operations in this reach apparently produce no damaging effects to shoreline structures.

Reach 9
Chart No. 63 — From a point just upstream from the International Bridge (above the Soo Locks) upstream to one mile south of Brush Point.
Photos 48-3, 48-5; 47-1 to 47-11.

Ice Conditions

Natural — Shore ice and often a more extensive ice cover form in this reach. Vertical movement of this ice occurs as a result of wind set-up in Lake Superior and

Whitefish Bay. Horizontal movement of the ice may occur under the influence of wind during break-up.

Navigation

The operation of vessels when ice is present in this reach apparently does not produce effects in the ice cover which impact on the shoreline. Presumably the vertical and horizontal movements imparted to the ice by navigation are insignificant compared to those which occur naturally.

APPENDIX B

Cost estimates for typical private shoreline structures in Great Lakes connecting channels

Type of structure	Cost
Walkway docks	
All wood construction, typical dimensions 30' to 100' long (in spans of 10'0), 3' to 4' wide, maximum water depths about 6', average 4'	$1448/span of 10'
End-dock platforms	
All wood construction, typical water depths 4' to 6'	

Length	Width	Number of piles	Cost
10	10	4	$1546/ea
15	10	6	2364
20	10	6	2430
15	15	9	3391
20	15	9	3500
20	20	9	3521

Type of structure	Cost
Pile clusters	
Wood piles, typically 4 piles per cluster, in water 4' to 6' deep	$1344/ea
Boat houses	
Single boat house, wooden, measuring 15' x 25', cost average between flat and gable roof, 3' and 6' water depth, and with or without manual cable winch boat lifting mechanism.	$5902/ea
Double boat house, wooden, measuring 25' x 25', same average criteria as above	$7460/ea
Boat shelters	
Single boat shelter, wooden, measuring 15' x 25', cost average between flat and gable roof, and 3' and 6' water depth	$4112/ea without boat lift $4952/ea with boat lift
Double boat shelter, wooden, measuring 25' x 25', same average criteria as above	$5200/ea without boat lift $6040/ea with boat lift

Boat lifts

Commercial steel pipe lift for small boat	$ 840/ea

Rubble-filled timber cribs

Typical dimensions 6' x 6', average water depth 4', maximum 6', typically four cribs per site	$11,004/four cribs at one site

Single mooring piles

Wood piles, typically 6' tall above water in 4' to 6' of water; average of five per site	$1680/five separate piles at one site

Platform boat ramps at shorelines

Wooden, typical size 6' x 15'	$ 262/ea

Sheet-pile bulkheads (residential)

Typical heights 2' to 3' above water	$ 150/lineal foot

Rubble mounds

Typical top dimensions 12' x 36', typical water depths up to 6'	$3080/ea

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